



Arc Jet Testing Of Carbon Phenolic For Mars Sample Return And Future NASA Missions

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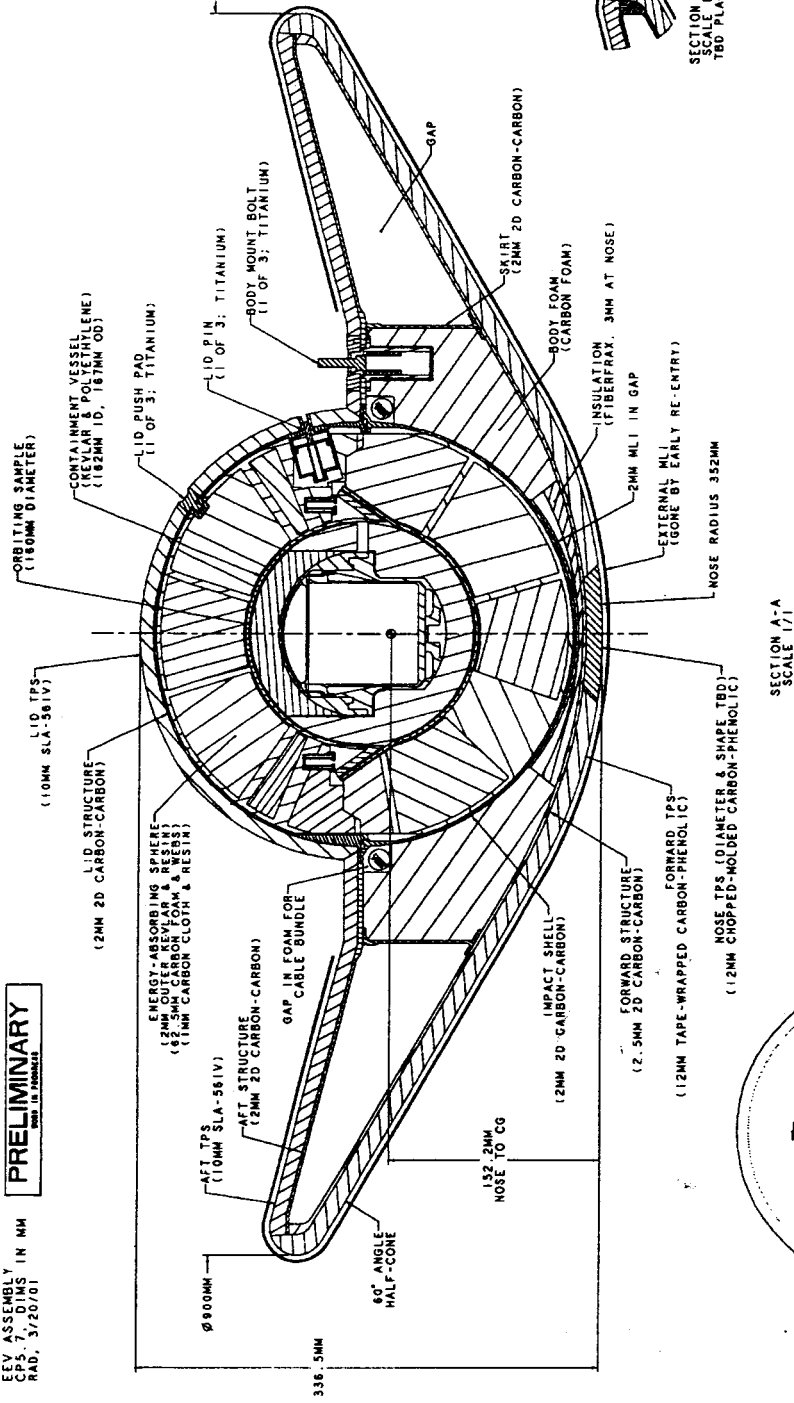
Mars Sample Return Mission



- The objective of the Mars Sample Return (MSR) mission is to return a sample of Martian soil to Earth.
- The Earth Entry Vehicle (EEV) brings the samples through the atmosphere to the ground.

EEV ASSEMBLY
CPS, 7-01MS IN MM
RAD, 3/20/01

PRELIMINARY
DRAWN BY: J. J. J. J.



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MSR EEV containment requirement



- Strict containment requirement by NASA's Planetary Protection Officer: less than 10^{-6} probability of releasing any Martian material within Earth's biosphere
 - Survival of EEV depends greatly on TPS performance
- $\Rightarrow$ high reliability EEV $\Rightarrow$ heritage TPS
- Heritage TPS material would be one with a history of successful survival in one or more previous NASA missions

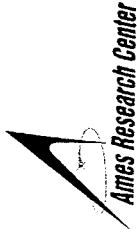


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Objectives



- Model aerothermal environment during EEV flight
- On the basis of these modeling results and historic performance, select potential TPS materials for EEV forebody
- Fabricate selected heritage TPS materials, as well as few alternate non-heritage materials
- Test these materials in the arc jet environment representative of predicted flight environment
- Evaluate materials performance in the arc jet
- Compare results of modeling predictions with the test results



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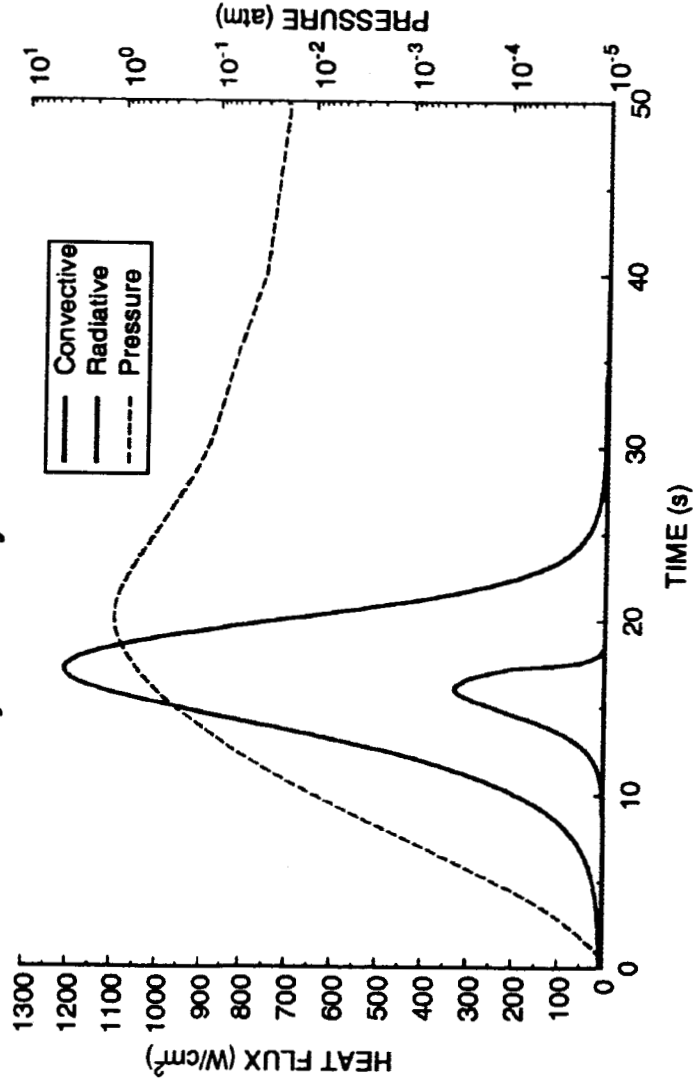


Anticipated stagnation point entry heating environment for EEV



- First step in TPS selection is analysis of aerothermal environment

Entry velocity 11.5 km/sec



- 1500 W/cm^2 peak

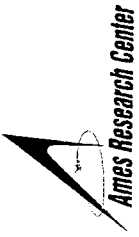
- 9.7 kJ/cm^2 stagnation

stagnation point heat flux point integrated heat load



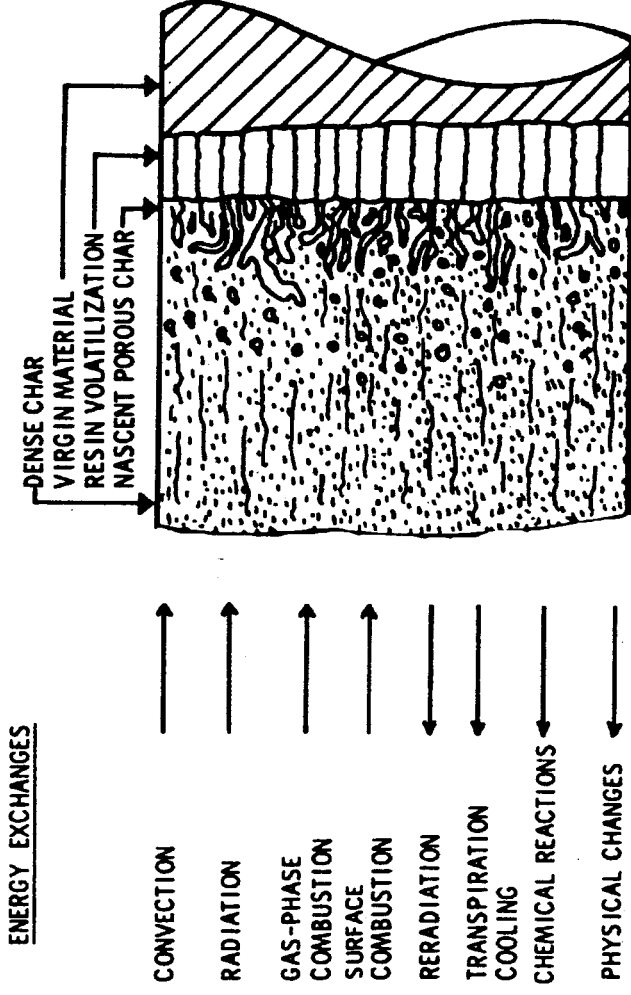
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TPS selection: why ablators?

- For heating rates of 1500 W/cm^2 ablators are the main choice



- Ablators can be used at extremely severe heating environments, where no other (ceramic-based) reusable materials can be used.
- Drawback is sometimes large recession -> change in aerodynamic shape

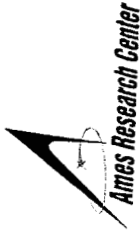


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TPS selection: Why fully dense carbon phenolic



Fully dense carbon phenolic ablative TPS showed success in Galileo and Pioneer Venus missions at conditions much more severe than expected for MSR EEV

Mission	Stagnation heat flux, W/cm ²	Integrated heat load, J/cm ²	TPS material
Pioneer Venus Large Probe	4,500	11,800	Carbon phenolic, $\rho = 1.49 \text{ g/cm}^3$
Galileo Probe to Jupiter	55,200	300,000	Carbon phenolic, $\rho = 1.45 \text{ g/cm}^3$
Mars Sample Return	1,500	9.7	Carbon phenolic, $\rho = 1.5 \text{ g/cm}^3$

Launch 1978

Launch 1989

Largest heat flux ever

Shuttle

30

Silica-based tile



Fully dense Carbon phenolic as TPS for MSR EEV

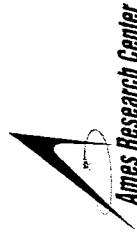


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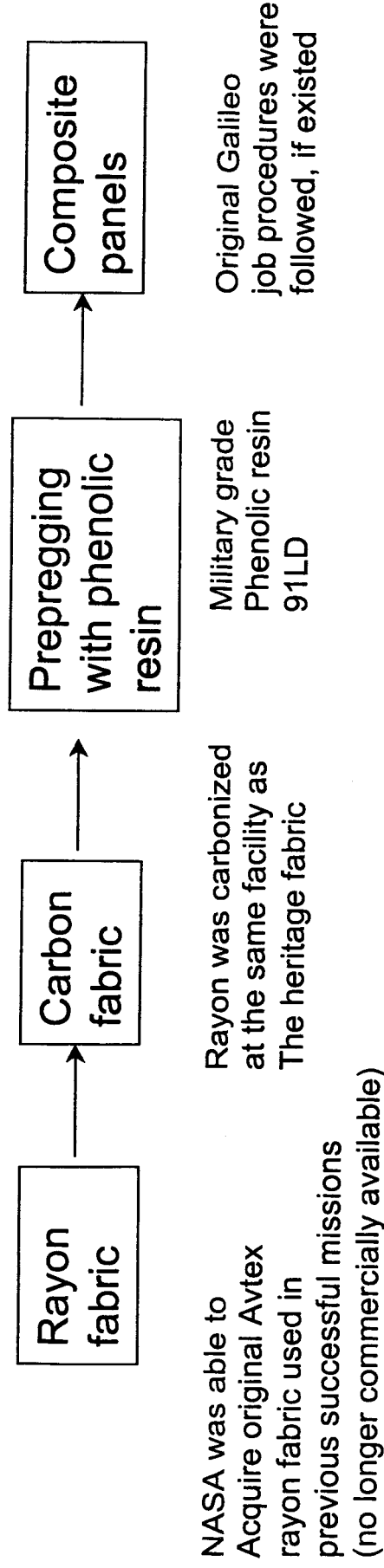
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TPS selection: fabrication of tested composites



- In order to fabricate "heritage" materials, original components and processes had to be found, i.e., ones that were used on Galileo probe
- All carbon phenolic composites were fabricated by outside vendors under NASA guidelines



- Supply of heritage materials for carbon phenolic composites is disappearing -> alternate materials were also tested

Lyocell carbon fiber: staple, larger thickness
Other grade of phenolic resin SC1008



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TPS selection: fabrication of tested composites



Both Galileo probe and MSR EEV use two types of composites:

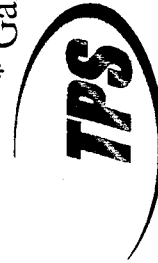
- Chopped Molded Carbon Phenolic (CMCP)
- Tape Wrapped Carbon Phenolic (TWCP)



Summary of fabricated and tested composite materials: 6 different materials

	Carbon Fabric	Phenolic Resin	Density, g/cm ³	
Tape Wrapped	CCA-3 (1641B) *	9ILD*	1.47	Galileo Pedigree fabric/resin system
	CCA-3 (1641B) *	SC1008	1.47	
30 °-angle ply	Lyocell	SC1008	1.33	
Chopped Molded	CCA-3 (1641B) *	9ILD*	1.45	
	CCA-3 (1641B) *	SC1008	1.42	
	Lyocell	SC1008	1.44	

* Galileo pedigree fabric and resin systems



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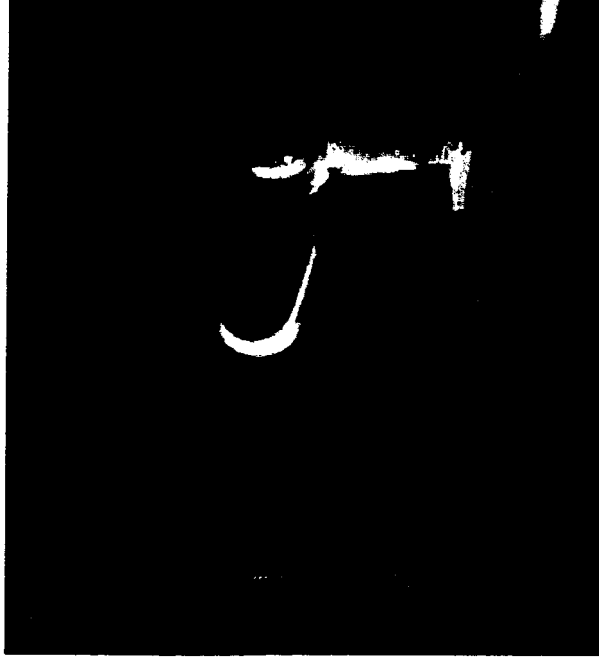
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Arc jet testing: Interactive Heating Facility (IHF)



- Materials were tested at IHF facility at NASA Ames
- 60 MW power



- Materials are tested in hypersonic plasma flow
- Arc jets simulate flight heating environment



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Arc jet testing: summary of test conditions



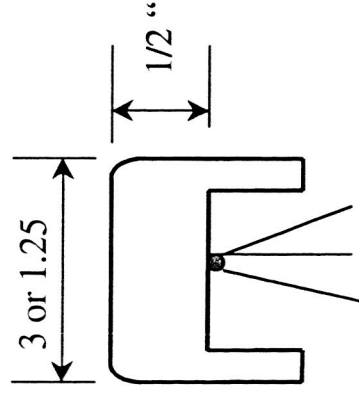
- Each material was tested at two heating conditions:
 - Maximum heat according to modeling predictions (1500 W/cm²)
 - Half of maximum heat flux (750 W/cm²)
- Similar integrated heat load as during flight

	Heat flux, W/cm ²	Exposure time, sec.	Total heat load, J/cm ²	Stagnation pressure, atm	Stagnation enthalpy, MJ/kg	Model diameter, inch
Condition 1	1500	6.5 (7)	9750 (10500)	1	28.1	1.25
Condition 2	750	13	9750	0.82	18.1	3
Flight	variable	trajectory	9650			

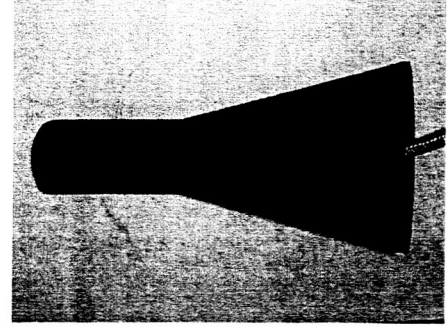
Test specimen geometry

Sketch of cross section

Attached to the holder



Thermocouples



Different diameter for high and low conditions due to arc jet restrictions

3 inch for 750 W/cm²

1.25 inch for 1500 W/cm²



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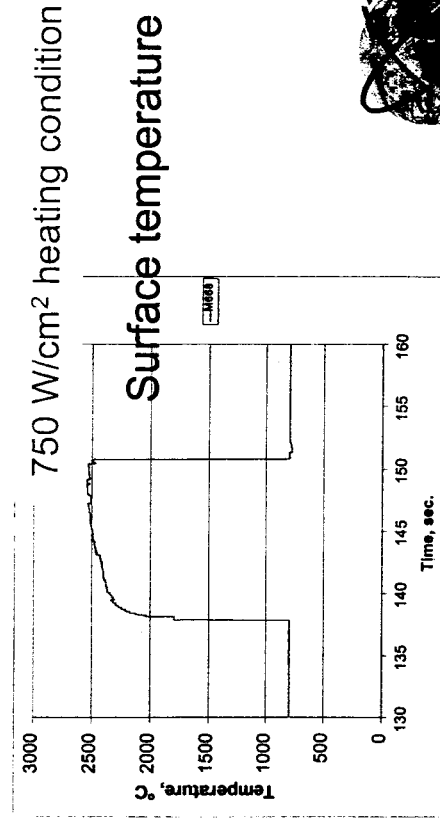
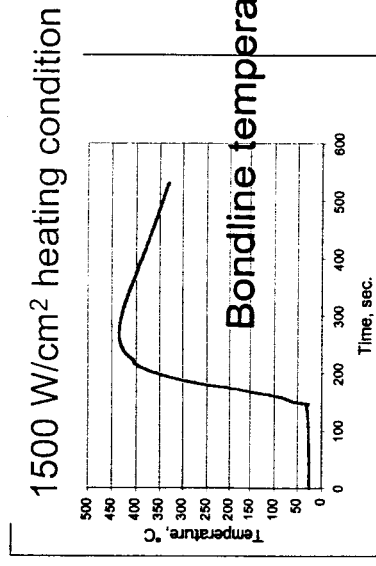
Criteria of material evaluation



1. Structural integrity post arc jet test
2. Surface recession



3. Bondline temperature and how close it can be predicted by modeling



4. Surface temperature

5. Weight loss



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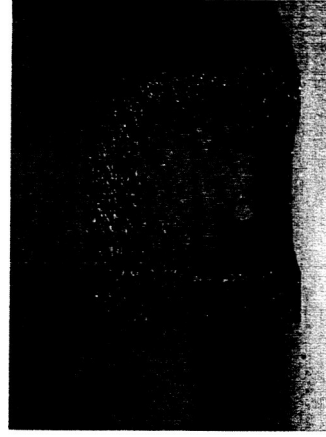
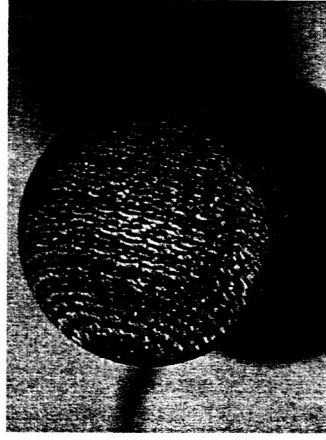
Arc jet test results: post-test visual appearance



Tape wrapped carbon phenolic

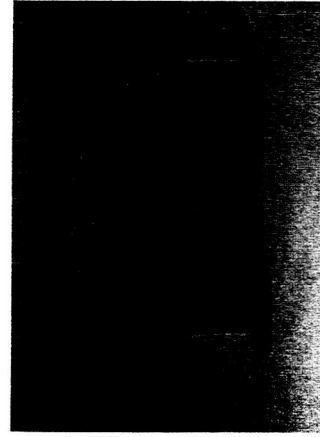
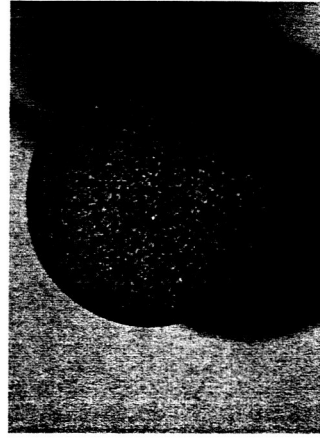
CCA-3/91LD

Sample ID: 91LD-7
Heritage material



Lyocell/SC1008

Sample ID: Lyocell-7



Tested at high heat flux
(1500 W/cm²)



- Some delamination for heritage material
- Lyocell/SC1008 didn't show much delamination



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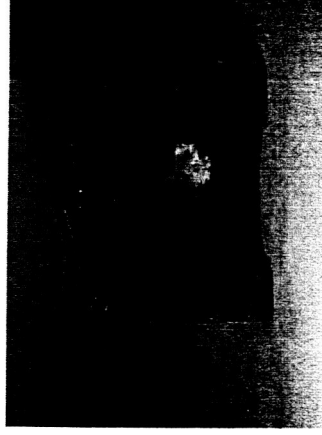
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Arc jet test results: post-test visual appearance



Chopped molded carbon phenolic

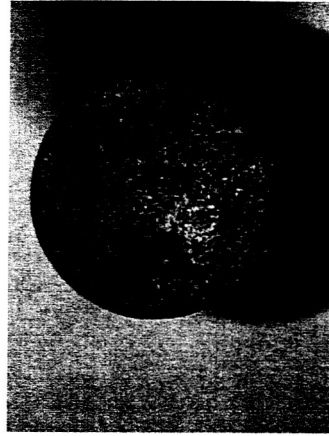


CCA-3/91LD

Sample ID: 91LD-7

Heritage material

Tested at high heat flux
(1500 W/cm²)



Lyocell/SC1008

Sample ID: Lyocell-7

- Both heritage and Lyocell materials showed slight delamination.



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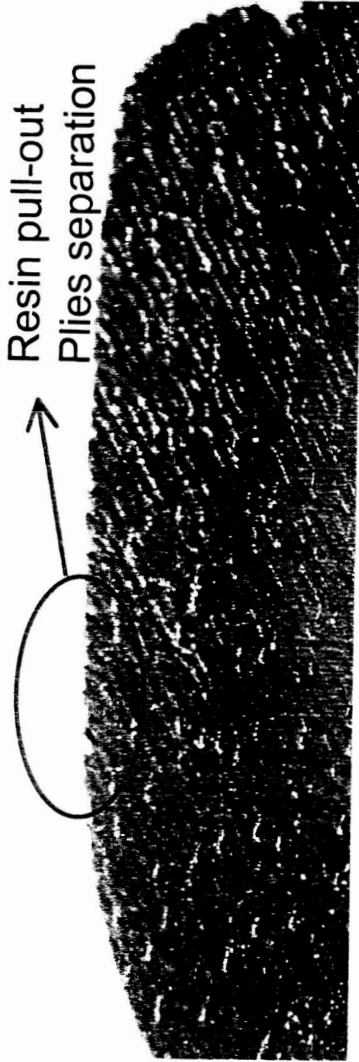
Arc jet test results: recession



CCA-3/91LD

Sample ID: 91LD-7

Heritage material



Lyocell/SC1008

Sample ID: Lyocell-7



- Very little or no recession was predicted.
- Due to resin pull-out, most of the samples increased in size (negative recession).
- Lyocell fiber composites didn't show much of ply separation due to staple character of Lyocell, and plies interlocking.



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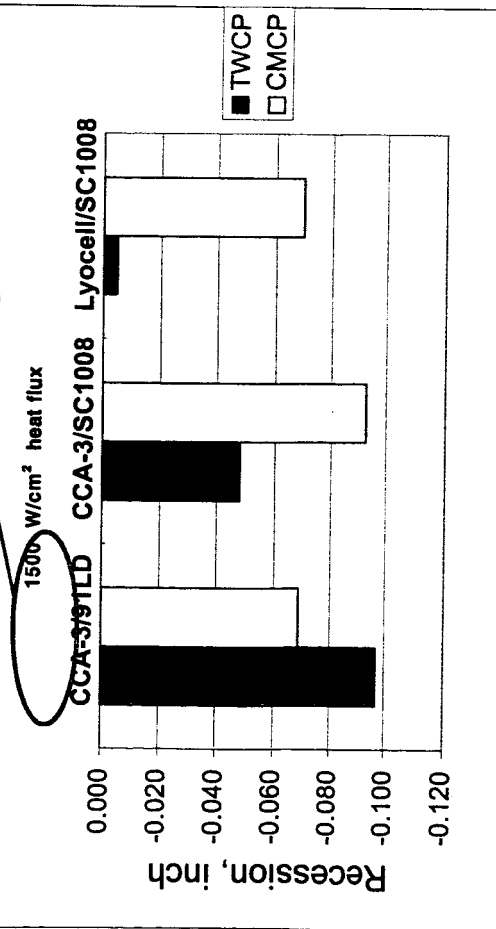


Arc jet test results: recession

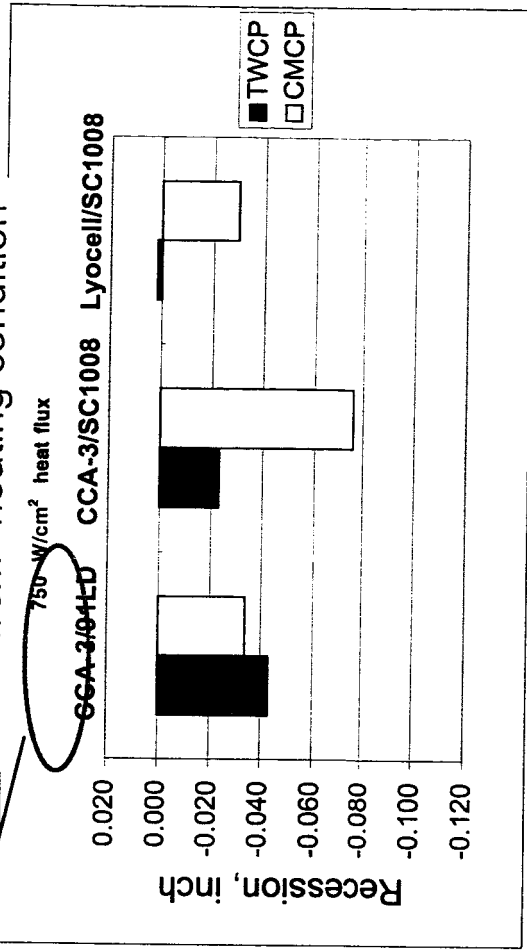


Heritage materials

1500 W/cm² heating condition



750 W/cm² heating condition



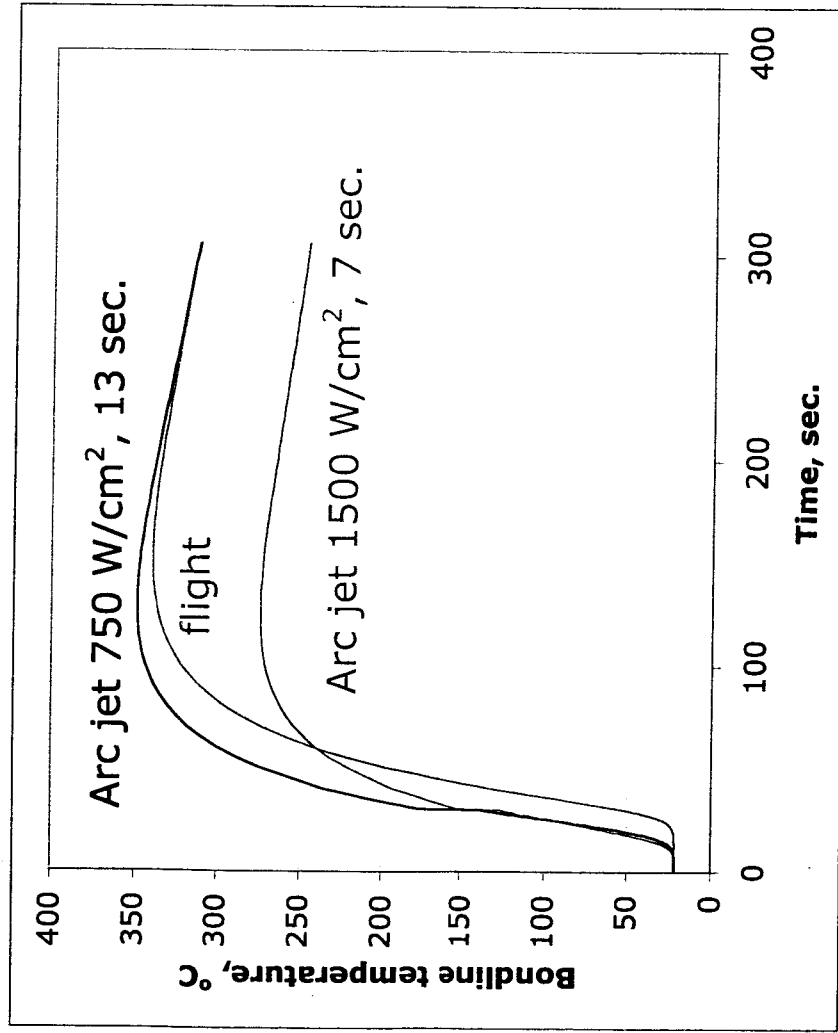
- Negative recession (increase in thickness) was observed in most cases due to swelling and/or delaminations.
- Lyocell fiber based composites showed the smallest size change.



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Predicted bondline temperatures



- Modeling predicts that arc jet testing at half of maximum heat flux should result in bondline temperature close to the flight conditions
- Testing at high heat flux should result in lower bondline temperature

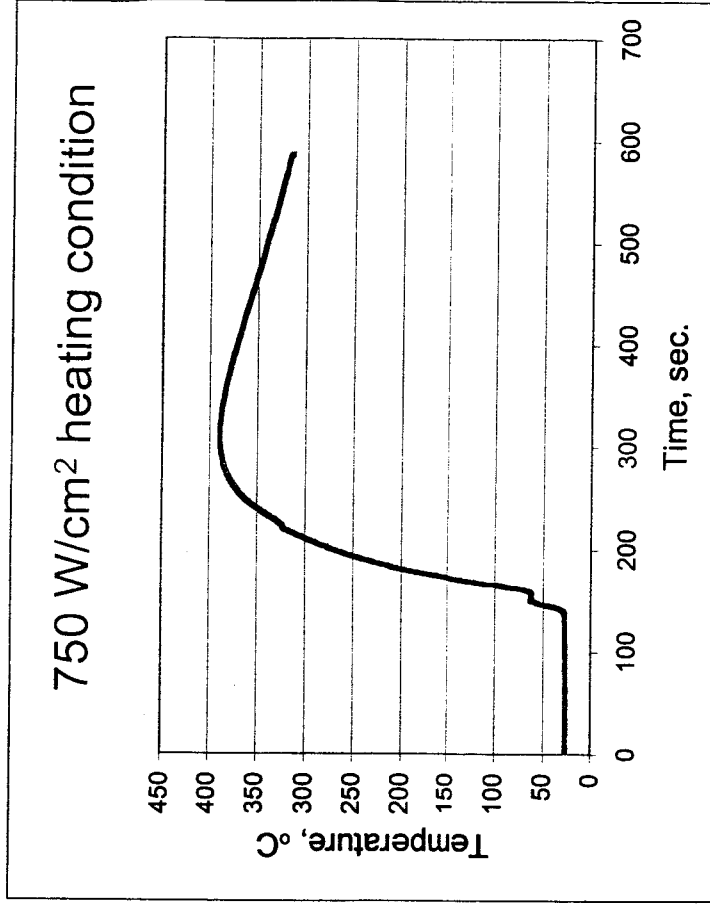
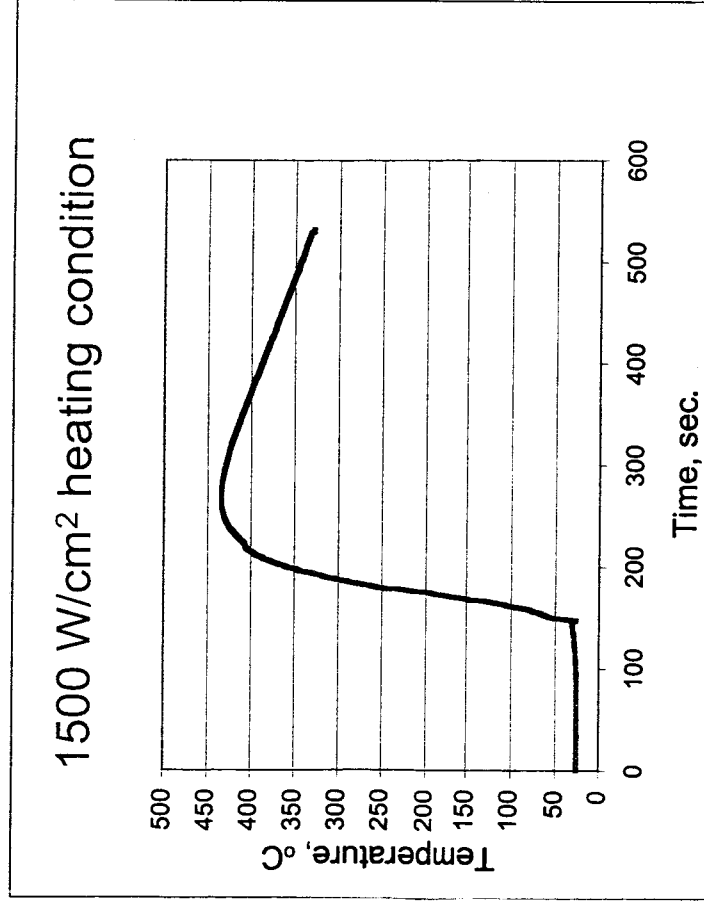
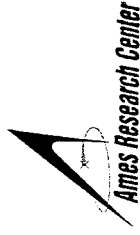


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Examples of bondline temperature response

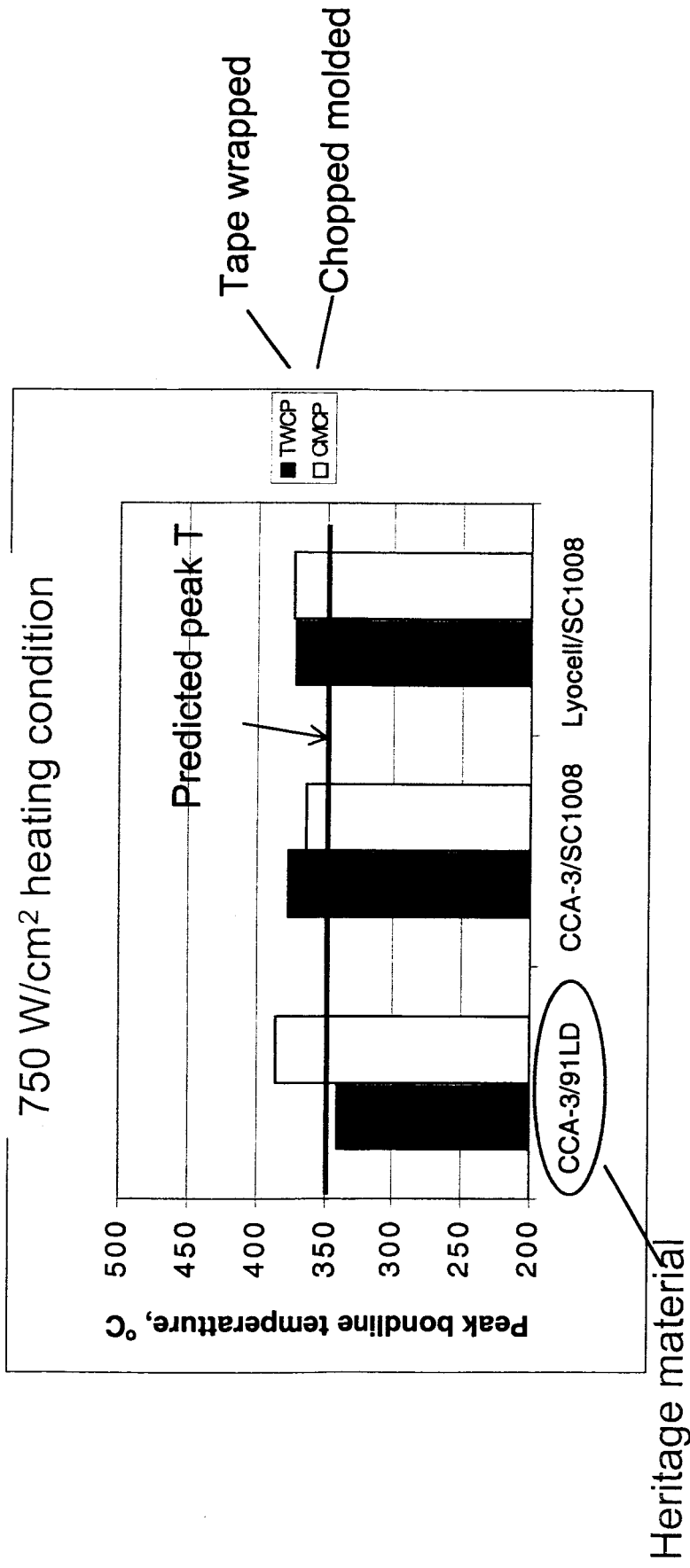


- Examples above are for the TWCP Lyocell/SC1008 material.
- Peak temperature is reached within a few minutes after the models are removed from the flow:
 - ~ 100 sec. for the 1500 W/cm² condition;
 - ~ 150 sec. for the 750 W/cm² condition.





Summary of peak bondline temperature



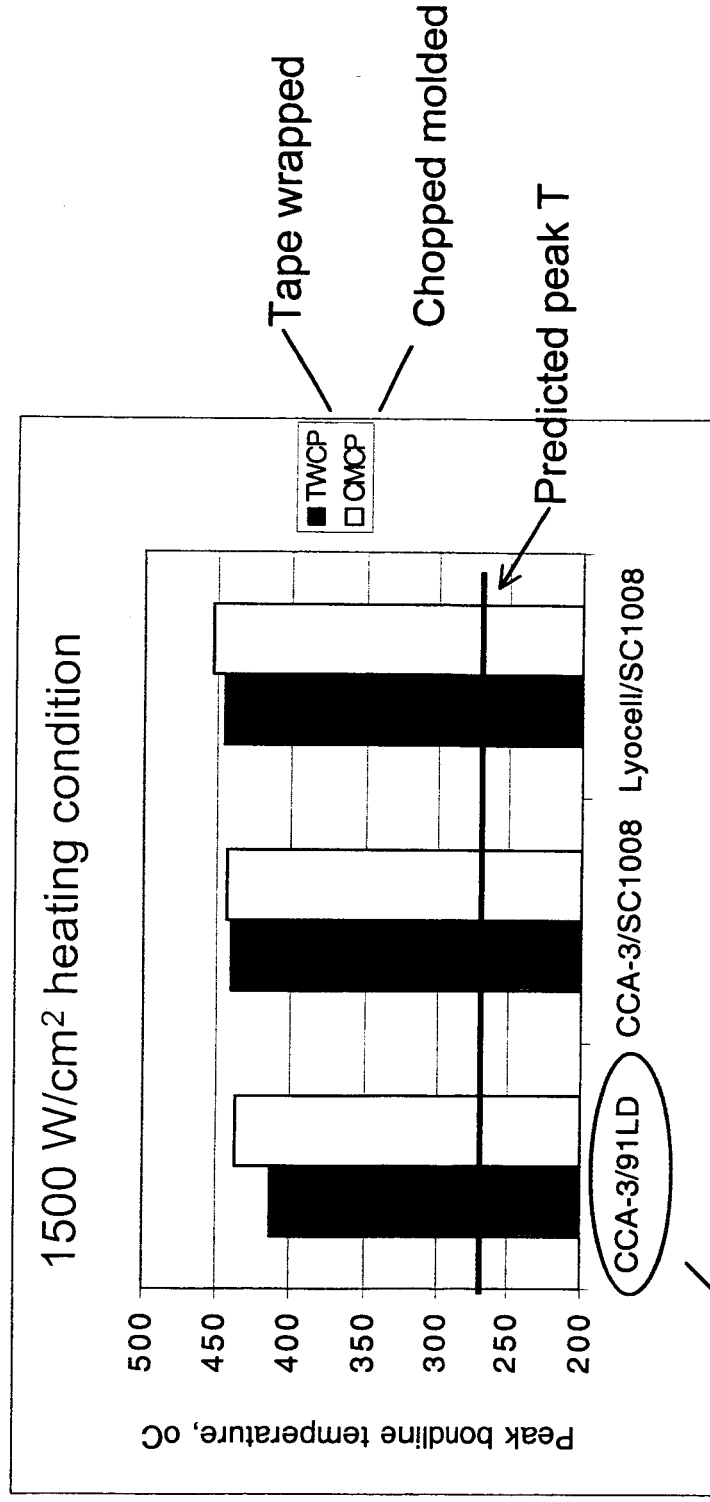
- All materials performed comparably to each other in terms of peak bondline temperature
- Slightly higher bondline temperature than predicted



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Summary of peak bondline temperature



Heritage material

- All materials performed comparably to each other in terms of peak bondline temperature

- Much higher peak bondline temperature than predicted!

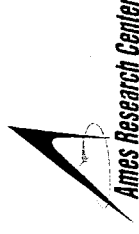


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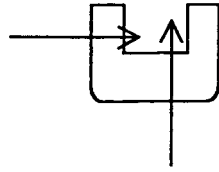
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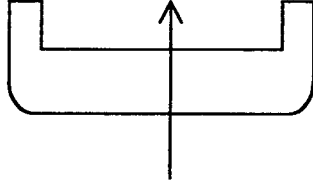
Discrepancy between measured and predicted bondline temperatures



1.25 inch diameter models tested 3 inch diameter models tested at 750 W/cm²
At 1500 W/cm²



Two-dimensional heat transfer at the center -> temperature is higher than predicted



~ One-dimensional heat transfer at the center -> experimental data agree with predictions

- Much higher peak bondline temperature than predicted for high heat flux
- This effect was expected due to the small model diameter resulting in 2-dimensional heat transfer effects during the arc jet test.

(Small diameter models (1.25 inch) were chosen for this test because of limitations of the IHF facility to achieve ~1500 W/cm² flux on larger size models).

- Modeling was done for one-dimensional case
- In order to correctly evaluate the backface temperature at high heat fluxes, larger size models need to be tested. (Small diameter models (1.25 inch) were



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Summary



- Potential thermal protection materials for Mars Sample Return Earth Entry Vehicle were tested in a series of screening arc jet tests
- Strict containment requirement for EEV dictated use of TPS with a heritage of successful flights in the past
- Fully dense carbon phenolic ablative TPS was selected as one with successful flight heritage (Galileo probe to Jupiter)
- The performance of the Galileo heritage and two other candidate TPS materials were evaluated at 1500 and 750 W/cm² heat flux
- The test series was successful and demonstrated that all the variant performed adequately at both heat fluxes and showed suitability for use as the forebody TPS for MSR EEV
- Theoretical models satisfactorily predicted bondline and surface temperatures for 3 inch diameter models tested at 750 W/cm² condition.
In order to fully characterize potential materials at high heat fluxes, testing of larger size models is necessary.



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